DØnote 4524-CONF

Reconstruction of Semileptonic Lambda-b Decays

The DØ Collaboration
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The decay $\Lambda_b^0 \to \Lambda_c^+ \mu^- \overline{\nu}_\mu X$ is reconstructed in data corresponding to approximately 350 pb^{-1} collected by the DØ detector between April 2002 and May 2004.

Preliminary Results for Summer 2004 Conferences

I. INTRODUCTION

This analysis has so far involved searching for semileptonic decays of Λ_b baryons in data taken by the DØ detector in Run II. These decays can be used along with decays of B_d mesons to measure the ratio of lifetimes of these two hadrons. The decays are due to the decay of the b quark, but the particular environment of light quarks and gluons also has an effect on the lifetime. The differences in lifetimes of hadrons containing a heavy quark are predicted to vanish as the mass m_Q of the heavy quark tends to infinity [1]. These effects have been predicted for B hadrons using a technique known as Operator Product Expansion(OPE). Using OPE the lifetime ratios of B hadrons have been predicted and are in reasonable agreement with experimentally measured values, except in the case of the Λ_b. For the ratio $\tau(\Lambda_b)/\tau(B^0_d)$ theoretical predictions, given their uncertainties, strongly favor values above 0.9, whereas the experimental evidence suggests values close to 0.8, with errors of approximately 0.05. Data taken at DØ at the high luminosity provided by the Fermilab Tevatron in Run II should allow a large Λ_b sample to be obtained and therefore allow a high precision measurement of this ratio, using a method similar to that described in [2].
The Λ_b decay searched for in this analysis is $\Lambda^0_b \to \Lambda^+_c \mu^- \overline{\nu}_\mu X$, where X is any other particle. Charge conjugates are implied throughout this paper. This decay has the advantage of a relatively high branching fraction, since the branching fraction for $\Lambda^0_b \to \Lambda^+_c l^- \overline{\nu}_l X$ is $7.7 \pm 1.8\%$ [3]. The selections were designed to reconstruct the Λ_c in the decays $\Lambda^+_c \to K^0_s p^+$ and $\Lambda^+_c \to \Lambda\pi^+$. Decays were reconstructed using data from approximately 350 pb^{-1} integrated luminosity, acquired by the DØ detector between April 2002 and May 2004. This note outlines the selections used to isolate the Λ_b decays and shows the signals obtained.

II. EVENT SELECTION

For each event the primary vertex was determined using the method described in [4] and the charged particles were clustered into jets using the DURHAM clustering algorithm [5]. Muons were selected using the standard DØ tools and were then also required to have at least two track segments in the muon chambers associated to a central track and a value of p_T of at least 2.0 GeV/c. The products from the decay of Λ_c were then searched for among tracks belonging to the same jet as an identified muon.

A. Selection of Λ and K_s

The Λ and K_s were reconstructed as V^0 decays to two oppositely charged tracks. These tracks were required to form a secondary vertex with χ^2 per degree of freedom of less than 25 and a distance d_{V^0} from the primary vertex of at least $4\sigma(d_{V^0})$ if $\sigma(d_{V^0})$ was less than 0.5cm. The two tracks were required to have no more than two hits in the tracking system between them before the secondary vertex and each track was allowed no more than one miss after the reconstructed vertex. A loose cut on the direction of the V^0 was also applied. The angle α_{V^0} between the momentum of the reconstructed particle and the vector from the primary to the secondary vertex in the axial plane was required to fulfill the condition $cos(\alpha_{V^0}) > 0.8$. The axial ϵ_T and stereo ϵ_L impact parameter projections of each track with respect to the primary vertex and their errors were calculated and the combined significance $(\epsilon_T/\sigma(\epsilon_T))^2 + (\epsilon_L/\sigma(\epsilon_L))^2$ was required to be greater than 9 for both tracks and greater than 16 for at least one track. Further selections were then applied to the tracks and reconstructed vertex. Any vertices containing the identified muon as one of the tracks were rejected and both tracks were required to have at least one hit in the Central Fiber Tracker. The particle reconstructed was required to have p_T of at least 0.7 GeV/c.
To search for decays of Λ the values for the mass of the V^0 when the decay products were assumed to be both permutations of proton and pion were calculated. These are plotted in Figure 1 for a small subsample of the events, where the peak due to Λ can clearly be seen. Similar plots were used to set a mass range of 1.109 GeV/c^2 – 1.120 GeV/c^2 for accepted Λ candidates. The width of the peak is approximately 2.8 MeV so these limits correspond to approximately 1.75σ below the central mass of 1.115 GeV/c^2 and 2.14σ above. If the mass of the combination with the proton having higher momentum was within this range, the V^0 was accepted as a Λ and assigned this mass. For candidates not accepted the mass of the combination with a higher momentum pion was compared with the mass range, and accepted if it was within this interval. The charge of the proton was used to determine whether the reconstructed candidate was a Λ or $\overline{\Lambda}$.

To select K_s the decay products of the V^0 were assumed to be $\pi^+\pi^-$ and its invariant mass was calculated. A typical plot of this mass distribution for a small sample of events is shown in Figure 2. Here the peak due to K_s is also clearly seen, at a central mass of 0.494 GeV/c^2. Using similar plots the mass interval that would be accepted as

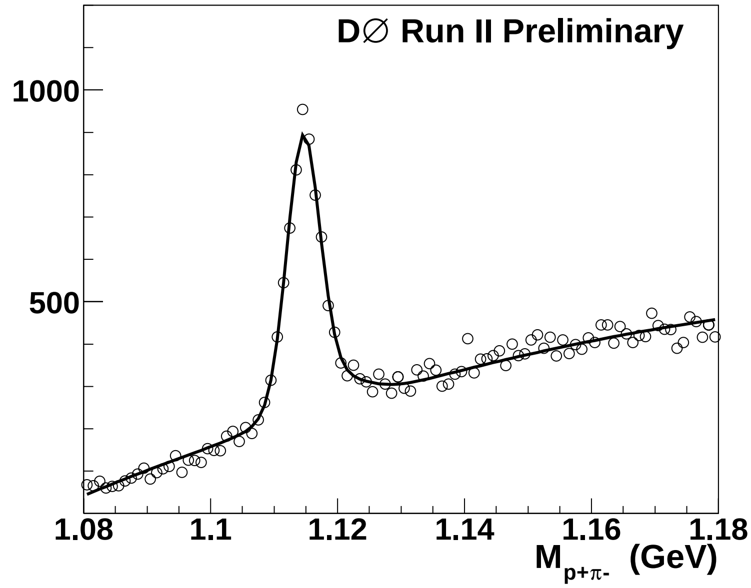

FIG. 1: The invariant mass of V^0 for decays to $p\pi$ in a small subsample of the data, showing the peak due to Λ at a mass of 1115 MeV/c^2.

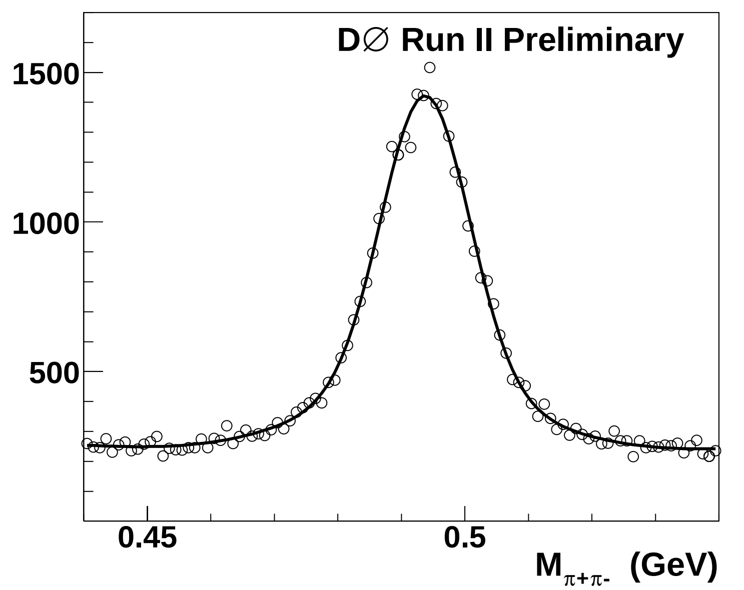

FIG. 2: The invariant mass of V^0 for decays to $\pi^+\pi^-$ in a small subsample of the data, showing the peak due to K_s at a mass of 494 MeV/c^2.

K_s was set at 0.480 GeV/c^2 – 0.5075 GeV/c^2. The width of this peak is approximately 7.6 MeV so these limits are both approximately 1.8σ away from the central mass.
If the mass conditions for Λ and K_s were both satisfied the V^0 was rejected.

TABLE I: Final cuts used for the two decay channels

	$\Lambda_c \to \Lambda\pi$	$\Lambda_c \to K_s p$
$cos(\alpha_T^c)$	> 0.84	> 0.91
$d_T^c/\sigma(d_T^c)$	> 3.6	> 3.8
$M(\Lambda_c/D+\mu)$	3.1–5.5 GeV/c^2	3.4–5.4 GeV/c^2
$P_T^{\Lambda_c}(\mu)$	> 0.35 GeV/c	> 0.35 GeV/c
$d_T^{bc}/\sigma(d_T^{bc})$	< 3.2	< 3.3
$(\epsilon_T/\sigma(\epsilon_T))^2 + (\epsilon_L/\sigma(\epsilon_L))^2$	> 3.2	> 4.6

B. Reconstruction of Λ_c

For each reconstructed Λ or K_s, the remaining tracks in the jet were searched for the proton or pion produced in the decay of Λ_c. Each track with $P_T > 1.0$ GeV/c^2 and at least 2 hits in the silicon detector was formed into a vertex with the Λ or K_s. The reconstructed vertex was required to have a value of χ^2 per degree of freedom less than 9. The reconstructed Λ_c candidate was then required to form a vertex with the muon. This vertex was also required to have χ^2 per degree of freedom less than 9. Reconstructed decay chains in which the Λ_c decay vertex was closer to the primary vertex than the Λ_b vertex were also rejected. To search for either of the decays it was then only necessary to assign the appropriate particle type to the track that was vertexed with the Λ or K_s candidate and plot the invariant mass of the new particle created in the vertex.

C. Selection Criteria

Other variables were calculated and their values used as selection criteria for all channels. The distance d_T^c in the axial plane between the Λ_c decay vertex and the primary vertex and the error on this distance $\sigma(d_T^c)$ were calculated and $d_T^c/\sigma(d_T^c)$ was used as a discriminating variable. Since the Λ_c candidate should be produced in a decay of a Λ_b and the b hadrons have relatively long lifetimes compared to charmed hadrons, this distance should be significant. The angle α_T^c in the axial plane between the flight direction of the Λ_c candidate and the vector from the primary vertex to the Λ_c decay vertex was also calculated and a minimum value was set for the $cos(\alpha_T^c)$. The transverse momentum $P_T^{\Lambda_c}(\mu)$ of the muon with respect to the direction of the Λ_c candidate was computed and cuts requiring a minimum value of this variable were used. The muon was also combined with the Λ_c candidate into a new particle, and the invariant mass of this combination was calculated and upper and lower limits were set for this mass. Due to the short lifetime of the Λ_c, a limit on the distance d_T^{bc} between the Λ_b and Λ_c decay vertices divided by its error was imposed. The combined impact parameter significance $(\epsilon_T/\sigma(\epsilon_T))^2 + (\epsilon_L/\sigma(\epsilon_L))^2$ of the Λ_c was calculated and events with this parameter below a certain value were rejected.
The cuts were optimized separately for each channel, the values used are shown in Table I. Some of these cuts will bias the lifetime distributions but in the case of measurement of lifetime ratios [2] this bias should not affect the final measurement.

III. RESULTS

A. K_s Events

For the events in which a K_s was identified the mass for the $K_s p$ hypothesis is plotted in Figure 3. The upper points show the reconstructed events in which the muon and D candidate have opposite charges as is expected in the decay $\Lambda_b^0 \to \Lambda_c^+ \mu^- \overline{\nu}_\mu X$. The lower histogram shows the wrong sign combination for the muon and the Λ_c candidate. Here a peak close to the PDG [3] value of the Λ_c mass of 2284.9 ± 0.6 MeV/c^2 is clearly observed in the plot for right sign events. This peak is almost 9σ above the background so this is very strong evidence that a signal is observed. However, semileptonic decays of B mesons will also be selected, and the reflection of these events in the M($K_s p$) mass spectrum may contribute to this peak. It is expected that the plots also contain contributions from the decays $\overline{B}_d^0 \to D^+ \mu^- \overline{\nu}_\mu X$ with $D^+ \to K_s^0 \pi^+$ and $\overline{B}_s^0 \to D_s^+ \mu^- \overline{\nu}_\mu X$ with $D_s^+ \to K_s^0 K^+$. A peak due to D and D_s from these decays is observed in the region between 1.81 GeV/c^2 and 1.92 GeV/c^2 if the mass of the $K_s \pi$ hypothesis is plotted. To check that reflection from this peak is not the cause of the peak in Figure 3, the events with $M(K_s \pi)$ between

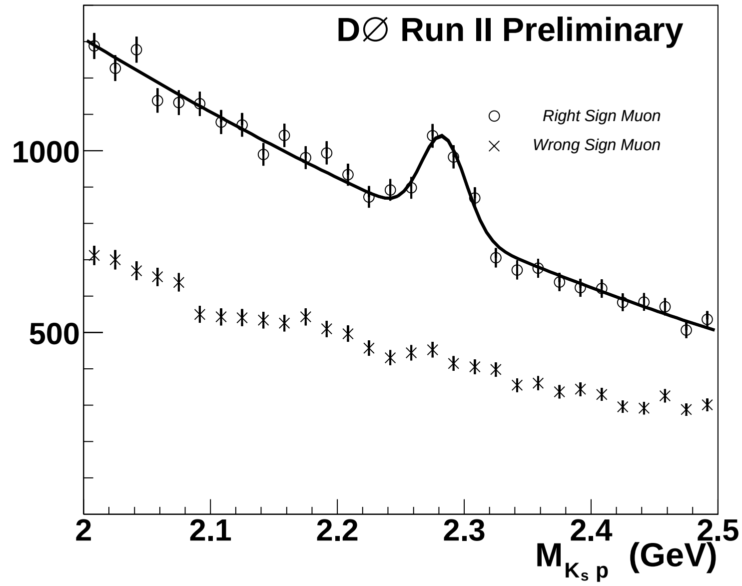

FIG. 3: The invariant mass of $K_s p$ for reconstructed decays containing a K_s, for right and wrong charge correlation with the muon. The fitted peak is at a mass of $2284 \pm 2.2(stat)$ MeV/c^2.

1.81 GeV/c^2 and 1.92 GeV/c^2 which survived the cuts were selected and the mass of the $K_s p$ hypothesis was plotted. This is shown in Figure 4, where it can be seen that these events are distributed over a wide mass range and the main peak is at a lower mass than the Λ_c, so the B meson decays mainly contribute to the background observed in Figure 3. A small peak of around 70 events is observed around 2.28 GeV/c^2 in Figure 4. This may be due to reflection of D and D_s events in the Λ_c mass range. However, this peak contains a small fraction of the events observed in the Λ_c signal, so the majority of the events in the peak in Figure 3 are due to Λ_b decays.

B. Λ Events

For events containing a Λ the mass $M(\Lambda\pi)$ is shown in Figure 5. Besides the peak close to 2.28 GeV/c^2 as expected, there is also an indication of another peak at a slightly lower mass. Therefore this plot has been fitted with the sum of two Gaussians and a quadratic background, where the widths of the two Gaussians were allowed to vary independently of each other. The peak at higher mass is approximately 6.3σ above the background and the lower peak is approximately 2.9σ. There is strong evidence for the signal of $\Lambda_c^+ \to \Lambda\pi^+$, but significantly higher statistics would be needed to confirm the existence of a signal for the lower peak. The lower peak is thought to be due to the decay $\Lambda_c^+ \to \Sigma^0\pi^+$. Σ^0 decays to $\Lambda\gamma$ close to 100% of the time, and has a very short lifetime, so it is likely that the Λ and pion have been found and reconstructed into a vertex for many of these decays. Since the photon is not included, these decays should cause a peak to be seen at about 74.5 MeV/c^2 below the mass of the Λ_c [3]. The mass difference shown on the plot is $78 \pm 11.4(stat)$ MeV/c^2. The branching fraction of this decay is given by the PDG [3] to be $(9.9 \pm 3.2) \cdot 10^{-3}$ whereas the decay to $\Lambda\pi$ has branching fraction $(9.0 \pm 2.8) \cdot 10^{-3}$, but using these selections a lower number of decays to $\Sigma^0\pi$ are observed. It should be also possible to use these decays in the later analysis, to increase the statistics for the Λ_b sample.

IV. CONCLUSIONS

Using the selections outlined in earlier sections and approximately 350 pb^{-1} of data taken by DØ in Run II the signal for semileptonic decays of Λ_b has successfully been isolated using reconstruction of Λ_c in the modes $\Lambda_c^+ \to K_s^0 p^+$ and $\Lambda_c^+ \to \Lambda\pi^+$. An indication of the decay of $\Lambda_c^+ \to \Sigma^0\pi^+$ has also been observed. This sample will be used in a

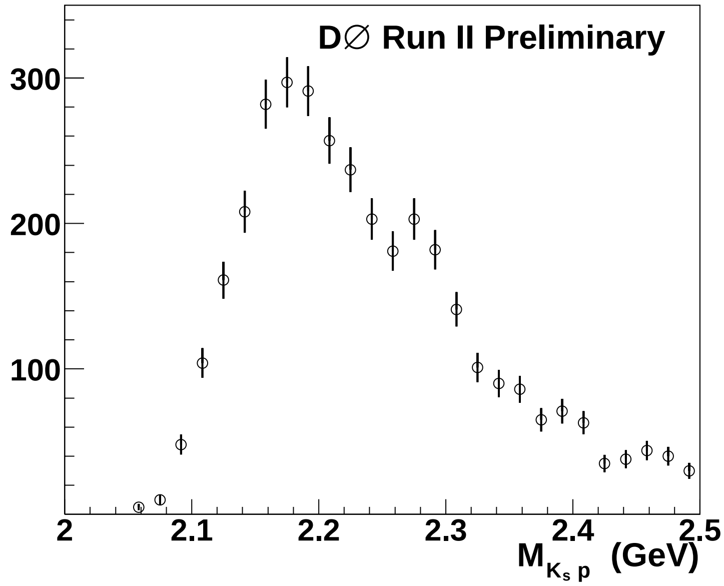

FIG. 4: Invariant mass of $K_s^0 p$ for right sign events passing the selection cuts used for $\Lambda_c \to K_s p$ with $M(K_s\pi)$ between 1.81 GeV/c^2 and 1.92 GeV/c^2.

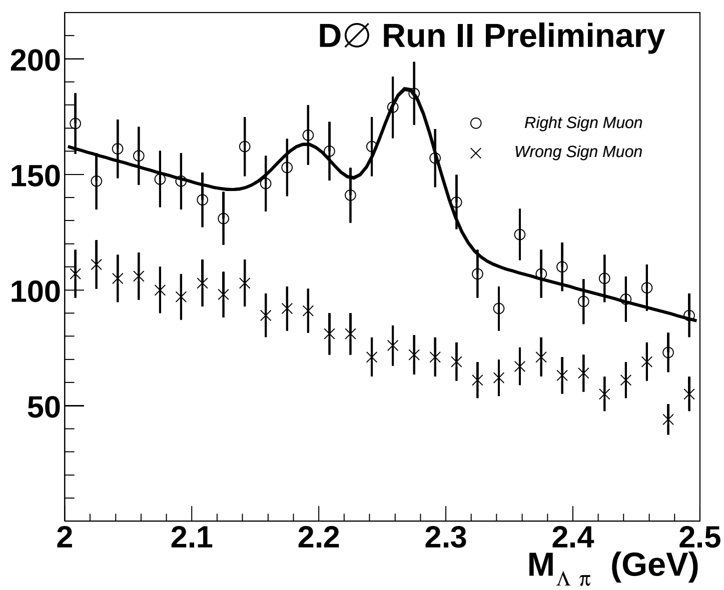

FIG. 5: Invariant mass of $\Lambda\pi$ for reconstructed decays containing a Λ, for both right and wrong sign charge correlation with the muon. The peak at higher mass is at $2271 \pm 5.0(stat)$ MeV/c^2, the lower mass peak is at $2193 \pm 10.3(stat)$ MeV/c^2 and is due to the decay $\Lambda_c^+ \to \Sigma^0\pi^+$ with $\Sigma^0 \to \Lambda\gamma$

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measurement of the lifetime ratio of Λ_b and B_d.

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